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Topical Area: Contributions of Radar Data to Water Management

USE OF WSR-88D RADAR DATA BY THE U.S. BUREAU OF RECLAMATION FOR WATER RESOURCES MANAGEMENT

Curtis L. Hartzell, Arlin B. Super and L. Albert Brower
U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado, USA

Corresponding author address: Curtis L. Hartzell, Bureau of Reclamation, Denver Federal Center, P.O. Box 25007, D-8510, Denver, CO, 80225-0007; e-mail: chartzell@do.usbr.gov

1. INTRODUCTION

The Bureau of Reclamation (Reclamation) serves over 31 million people in the 17 contiguous western States of the USA, providing over 9.3 trillion gallons of water each year. Accurate and timely hydrometeorological information is essential for the efficient management of these water resources. Over the past decade, the National Weather Service (NWS), in partnership with the Federal Aviation Administration, and the Department of Defense, has installed a combined network of about 160 WSR-88D (Weather Surveillance Radar - 1988 Doppler) radar systems throughout the USA and at selected overseas sites. This network of modern S-band radar systems is also know as the NEXt generation weather RADar (NEXRAD) system. The NEXRAD system provides precipitation information that is readily visible to the general public (TV weather, Internet). A great potential exists for agencies such as Reclamation to apply enhanced NEXRAD precipitation products for improving the efficiency of their water resources operations and reducing risk of loss from extreme precipitation events.

Various Reclamation and other users could benefit from near real-time rainfall or snowfall estimates customized for their particular area of interest. NEXRAD can be used to provide improved rainfall estimates over watersheds draining into reservoirs with flash flood potential. Agricultural water districts could conserve water, and individual irrigators could improve their on-farm operations, if NEXRAD rainfall estimates were coupled with evapotranspiration (ET) models to provide better estimates of water need. Because NEXRAD provides continuous spatial and temporal coverage of most of the 17 Western States (mountain blockage is a problem for some areas), many water managers could benefit from radar-estimated precipitation used as input to practical rainfall-runoff models. Such models are often linked into water resource operations models and decision support systems. This paper presents Reclamation's progress in developing and implementing NEXRAD enhanced decision support systems.

2. THE AWARDS SYSTEM

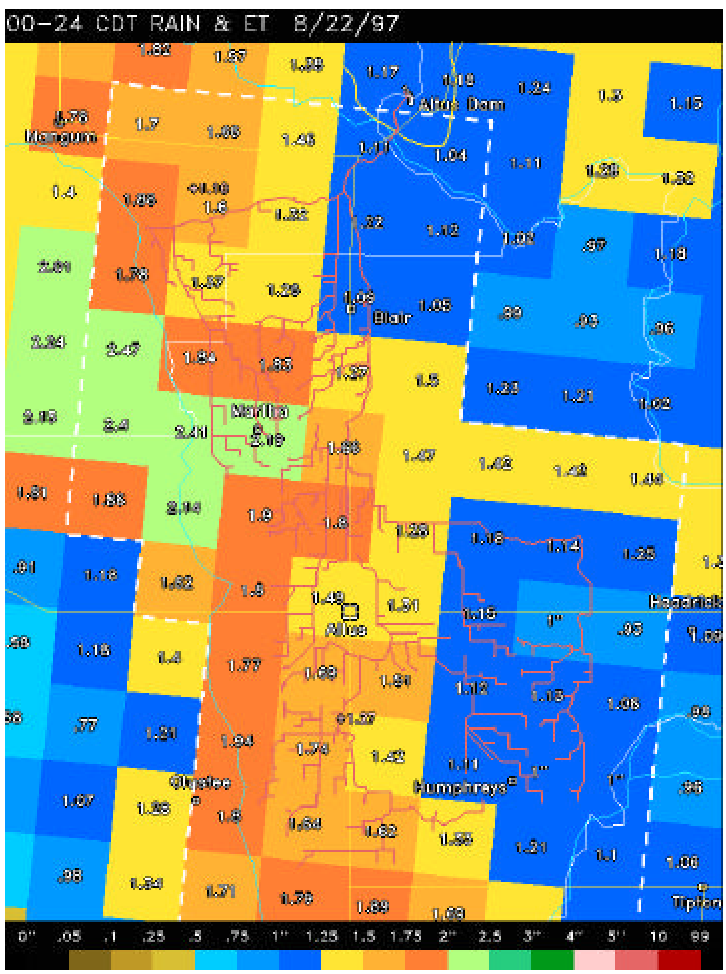
Reclamation's initial work to make operational use of NEXRAD rainfall estimates was the development of an automated information system to assist water users. The result, called the Agricultural WAter Resources Decision Support (AWARDS) system, provides easy access to rainfall and daily crop water use estimates.

The purpose of the AWARDS system is to improve the efficiency of water management and irrigation scheduling, by providing guidance on when and where to deliver water, and how much to apply. The AWARDS system is based on modern remote sensing, communication, computer, and Internet technologies. The current AWARDS system works as summarized below.

- NEXRAD radar systems measure equivalent reflectivity factor (Z_e) data as input to the Precipitation Processing System (PPS). The PPS produces the hourly Digital Precipitation Array (DPA) for each radar system (Level III, Stage I).
- Automated surface weather stations collect real-time data.

- Radar and surface weather data are transmitted to NWS computers for processing; the 13 NWS River Forecast Centers produce NEXRAD Level III, Stage II and III products.
- The AWARDS system computer automatically collects digital format data files of Level III, Stage III radar rainfall estimates, surface weather station data, and NWS precipitation forecasts from the NWS and other agency computers.
- The AWARDS system computer prepares the rainfall image and chart products for Internet access.
- Reservoir operators, water managers, and on-farm water users access the AWARDS system products via the Internet.
- Reservoir operators, water district staff and on-farm irrigators make operational decisions based on guidance information provided by the AWARDS system

The AWARDS system information and products are available from Reclamation's NEXRAD Web page http://www.usbr.gov/rsmg/nexrad/. The figure below shows an example of an interactive AWARDS system image for the Lugert-Altus Irrigation District, located in southwestern Oklahoma. The NEXRAD Hydrologic Rainfall Analysis Project (HRAP) (Greene and Hudlow, 1982) grid cells (about 4 X 4 km) in the figure show the estimated 24-hr (midnight to midnight local time) average rainfall (inches) for each cell. Also shown (at + signs) are the locations of two Oklahoma Mesonet weather stations. The irrigators can click a computer mouse on the HRAP grid cells within the dashed line boundary for pop-up estimated Crop Water Use (ET) charts, and can click on the weather stations for pop-up Daily Weather charts.



Reclamation is presently working on transporting the AWARDS system technology for use in the Rogue and Tualatin River Basins in western Oregon, and the Rio Grande River Basin in New Mexico.

3. NEXRAD-ENHANCED EARLY WARNING SYSTEMS

Reclamation is designing Early Warning Systems (EWS) for watershed/reservoir/dam systems to provide enhanced public safety to populations at risk downstream of the dam structures. The EWS designs are comprised of the following components: (1) a method for **detecting** flash-flood events; (2) a **decision making** process; (3) a means of **communicating** warnings between operating personnel and local public safety officials; and (4) a means for local public safety officials to effectively communicate the **warnings** to the public and carry out a successful **evacuation** of the threatened population at risk (Fisher, 1993). Similar to the AWARDS system application, use of near real-time (< one hour after sampling) NEXRAD data to estimate rainfall over upstream watersheds should enhance existing reservoir and dam EWS. NEXRAD should be able to pinpoint the cores of heavy convective storms. The hourly DPA data are available about 45 minutes past each sampled hour. Such data should, in most cases, provide alerts before the runoff is measured by a stream gage.

The watershed/reservoir/dam system selected for initial development of a NEXRAD-enhanced EWS was above Olympus Dam and Lake Estes near Estes Park, Colorado. The Olympus Dam EWS is an excellent example of the type of surface EWS that Reclamation is developing. The watershed above Olympus Dam covers a limited area of about 400 km^2. The EWS hardware consists of 11 stations with multiple sensors, including 10 precipitation gages, 9 stream gages, 2 reservoir level sensors, and 4 temperature sensors. Two of the stations also measure wind speed and direction, atmospheric pressure, relative humidity, and fuel moisture. These monitoring stations transmit data via line-of-site VHF radio to a repeater site which splits off a microwave signal that is placed into Reclamation's Eastern Colorado Area Office microwave system. The data are received at three independent EWS base stations, located at the Eastern Colorado Area Office (microwave), the Estes Power Plant (VHF), and the Reclamation - Western Area Power Administration (WAPA) Joint Operations Center. Requirements for the NEXRAD-enhanced EWS for the Olympus Dam watershed include the following:

- Automatically obtain NEXRAD Level III, Stage III hourly DPA data files via ftp from the NWS Missouri Basin River Forecast Center.
- Automatically obtain digital format hourly rainfall accumulations from the 10 EWS tipping-bucket rain gages.
- Develop a computer program for a UNIX-based computer workstation to automatically retrieve and process NEXRAD and EWS rainfall data each hour.
- Coordinate with the Olympus Dam EWS alert decision makers to establish critical rainfall values for the entire watershed and each subbasin.
- Develop a computer program to calculate each hour the storm total cumulative rainfall and hourly mean rain water volume for the entire watershed and each subbasin.
- Develop a procedure for a workstation to automatically send scripted e-mail alerts via a reliable satellite paging system.
- Develop a program for a workstation to prepare the rainfall image and chart products, and to make them available in near real time for Internet access.

3.1 NEXRAD Rainfall Data

The Olympus Dam watershed is scanned by both the Denver and Cheyenne WSR-88D radars. The Denver (or Front Range) WSR-88D radar is located about 105 km SE of the watershed, and the Cheyenne radar is about 110 km NE of it. At these ranges and azimuths, the radar beams for the lowest-available 0.5° tilt angle are partially blocked, but less than 50 percent. With less than 60 percent blockage, the PPS algorithm adds a predetermined dBZ value to each partially-blocked range bin ($dBZ = 10Log_{10}Z_e/1\ mm^6\ m^{-3}$). Both the Denver and Cheyenne radars should provide good rainfall estimates over the Olympus Dam watershed. Therefore, the following actions have been taken:

- Arrangements have been made with the Missouri Basin River Forecast Center to automatically ftp NEXRAD Level III, Stage III digital precipitation data to Reclamation's Technical Service Center about 45 minutes after the end of each sampled hour.

- A UNIX computer program has been developed to display the hourly and storm cumulative NEXRAD rainfall estimates on the HRAP grid, and to calculate rain water volume over subbasins of the Olympus Dam watershed each hour.

3.2 EWS Rainfall Data

The installation of the 10 tipping-bucket rain gages was completed during the summer of 1997. The gages include NovaLynx Model 2500 (heated) and NovaLynx Model 2501 (non-heated) tipping bucket gages. All gages are non-shielded with 8 inch diameter orifices. Since flash floods are not a problem during the winter season, all-season gages were installed at only 2 of the 10 sites. It is anticipated that these 10 tipping-bucket rain gages within the watershed can be used for comparison with the NEXRAD rainfall estimates. Also, they will continue to be used as designed for the current EWS (without NEXRAD rainfall estimates). This will permit comparisons to be made between the two rainfall estimating techniques.

3.3 EWS Automatic Alerts

Quickly getting heavy rainfall alerts to EWS decision makers is just as critical as making near real-time rainfall estimates over the watershed. The method for providing alerts makes combined use of computer and satellite paging system technologies. Whenever the computer program detects that the hourly or cumulative rainfall exceeds predefined limits, the program will prepare a scripted e-mail alert, which will be sent out immediately via a reliable satellite paging system. Testing of the NEXRAD-enhanced EWS for the Olympus Dam watershed is planned for the summer of 1998. These tests will include storm case study comparisons of EWS station rain gage measurements with NEXRAD Level III, Stage III rainfall estimates. Consideration will be given to adjusting the NEXRAD rainfall estimates with surface rain gage observations.

4. NIDS PRODUCTS FOR RADAR RAINFALL ESTIMATION

The NEXRAD rainfall estimates presently used with the AWARDS system, and with the developing NEXRAD enhanced EWS system for the Olympus Dam watershed, are the merged (among radars) Level III, Stage II hourly DPA files, which are called Stage III. Special arrangements have been made to receive these digital data files via automatic ftp from a number of NWS River Forecast Centers. As previously noted, these files arrive about 45 minutes after the end of each sampled hour. These digital data files use the HRAP grid which has a spatial resolution of about 4.0 X 4.0 km in Oklahoma. However, the HRAP grid cell size increases with latitude, e.g., grid cell length is 4.36 km at 45° north latitude.

The Stage III hourly DPA has a high-resolution accumulation (A), using 256 data levels with logarithmic 0.125 dBA intervals. The HRAP grid cell size seems to be sufficient for the AWARDS system. However, it is not clear whether the 45 minute delay in receiving the previous hour's data, and the approximate 4 X 4 km spatial resolution, will be adequate for EWS use. If not, how can the temporal and/or spatial resolutions be improved, and what are the tradeoffs? Another consideration when using Stage III is that there can be a problem with the data in areas of overlapping WSR-88D 230 km range umbrella coverage. Currently, Stage II precipitation fields are merged by averaging non-zero precipitation accumulations to generate the Stage III analysis. However, a previous study (Pereira et al., 1996) showed that wherever WSR-88D 230-km surveillance areas overlap, analysis errors associated with the well-known radar precipitation underestimation at far ranges adversely affect the current merging process where each radar is given equal weight.

4.1 NIDS Reflectivity Data

In addition to using Stage III data obtained by special arrangements with NWS River Forecast Centers, there is another basic approach for providing near real-time NEXRAD precipitation estimates. This approach would be to obtain near real-time NEXRAD observations of Z_e from a NEXRAD Information Dissemination Service (NIDS) vendor. Klazura and Imy (1993) discussed the NIDS products, and note that, with the exception of the three NEXRAD agencies, private organizations and government agencies will usually not have real-time direct access to WSR-88D data. That is, the NEXRAD system is designed so that almost all non-NEXRAD agency users are expected to use NIDS vendors for obtaining near real-time products.

The highest resolution Z_e data recorded are called Level II, with 0.5 dBZ intervals and single range bin (1° X 1 km) spatial resolution. Level II data are used as input to the PPS algorithm calculations associated with each WSR-88D. However, Level II observations are rarely available to non-NEXRAD agency users in real time.

Level III reflectivity data are a NIDS product available for the four lowest radar antenna tilts soon after each volume scan in the same range bin spatial resolution as Level II data (1° X 1 km). But Level III Z_e observations are "degraded" to 5.0 dBZ resolution in precipitation scanning mode (4.0 dBZ in clear air mode). The lower reflectivity resolution is presumably because the Level III reflectivity product is intended to be graphically displayed with up to 16 levels of color. More levels (colors) would be difficult to interpret. One negative result from using Level III NIDS reflectivity observations in place of the Level III, Stage III DPA would be that the accumulation resolution would be degraded from 256 to 16 levels.

4.2 Precipitation Accumulation Algorithm

Reclamation has recently developed the means to use Level III reflectivities as input to a Snow Accumulation Algorithm (SAA). Reclamation meteorologists and programmers began development of an SAA for the NEXRAD Operational Support Facility in June 1995. The ongoing SAA development was described in detail by Super and Holroyd (1996, 1997a) and an overview was presented by Super and Holroyd (1997b). SAA development is continuing with special data sets from each major snow region of the USA.

The SAA was tested in real time during the 1996-97 winter at the Cleveland and Minneapolis National Weather Service Forecast Offices where Level II reflectivities were available as input. Reasonable results were obtained as discussed by Naistat et al. (1998) for the Minneapolis region. But Reclamation will not have Level II data available, so the SAA has been modified to use Level III reflectivites decoded from the 16 level graphical product available through NIDS vendors. Further testing is needed, but initial SAA runs with both Level II and Level III data for Minnesota snow storms indicates quite reasonable agreement. That is, degrading the Z_e measurements from 0.5 to 5.0 dBZ resolution does not appear to result in serious degradation of snow water equivalent estimation over several hours.

The SAA is constructed so that "hybrid scans" are customized for individual radars based on data from actual snow storms. These SAA hybrid scans can later be easily modified if noticeable ground clutter frequently appears at particular range bin locations. The NEXRAD PPS also uses a customized hybrid scan at each WSR-88D, based on calculations of standard refraction beam height relative to terrain elevation files. The PPS attempts to locate the beam center closest to 1000 m above the radar, while ensuring that the calculated beam bottom is at least 150 m above local terrain and any beam blockage closer to the radar is less than 50 percent for the particular radial. For flat terrain the PPS hybrid scan specifies use of approximately the 3.4° (4th lowest) tilt beam to 20 km range, 2.5° to 35 km, 1.5° to 50 km and finally the lowest available 0.5° beam beyond 50 km. The result of these "steps" is often very apparent, especially with shallow storms where the vertical profile of Z_e has maximum values near the ground. Abrupt increases in estimated precipitation are calculated just beyond the ranges where the next-lowest tilt is selected by the PPS hybrid scan, causing a lower portion of the cloud with higher Z_e to be illuminated by the radar.

The SAA can easily be modified into a Precipitation Accumulation Algorithm (PAA) that includes rain by changing the Z_e-R relationship (where *R* is precipitation rate) into one appropriate for rain in the region of interest, and making a few other adjustments. This PAA would be equally capable of estimating high-resolution spatial and temporal rainfall estimates. Reclamation is planning to develop and test such a PAA. Then tests similar to those done for the SAA, i.e., comparing Level II and Level III dBZ resolutions, should be made with rain over shorter intervals to determine whether Level III reflectivity observations are adequate for use with EWS and rainfall-runoff models.

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